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Structural Geology of the Southern Part of Clarkston Mountain, Malad Range, Utah

Wayland E. Gray
Utah State University

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STRUCTURAL GEOLOGY OF THE SOUTHERN PART OF
CLARKSTON MOUNTAIN, MALAD RANGE, UTAH

by

Wayland E. Gray

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Geology

Approved:

__________________________
Major Professor

__________________________
Committee Member

__________________________
Committee Member

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Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

1975
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The writer wishes to acknowledge the technical assistance received from the staff of the Department of Geology of Utah State University. Appreciation is expressed particularly to Dr. Clyde T. Hardy who suggested the problem, spent numerous days in the field, and criticized the manuscript. A grant from the Gulf Oil Corporation was provided during the last year of studies and is greatly appreciated.

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Wayland E. Gray
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ABSTRACT

Structural Geology of the Southern Part of Clarkston Mountain, Malad Range, Utah

by

Wayland E. Gray, Master of Science
Utah State University, 1975

Major Professor: Dr. Clyde T. Hardy
Department: Geology

The mapped area, in north-central Utah, is located west of Clarkston, Utah. It includes the southern part of Clarkston Mountain and part of the Junction Hills, which extend southward from Clarkston Mountain. The area is represented on the southeastern part of the Portage quadrangle, Utah-Idaho, and the southwestern part of the Clarkston quadrangle, Utah-Idaho. It measures about 8.3 miles in the east-west direction and 4.0 miles in the north-south direction.

The southern part of Clarkston Mountain consists of stratigraphic units that range in age from Cambrian to Silurian. The Nounan Formation of Cambrian age is the oldest. The St. Charles Formation, of Cambrian age, and the Garden City and Swan Peak Formations, of Ordovician age, overlie the Nounan. The youngest unit consists of undifferentiated Fish Haven and Laketown Formations. The Fish Haven is Ordovician and the Laketown is Ordovician and Silurian. In the Junction Hills, the Oquirrh Formation of Pennsylvanian age crops out south of an east-west fault. It is overlapped unconformably by the Salt Lake Formation.
of Tertiary age. The Lake Bonneville Group of Quaternary age is present in Malad Valley, on the west, and in Cache Valley, on the east.

The rocks of the southern part of Clarkston Mountain dip east. A low-angle thrust fault is present on the eastern side of the mountain. It dips west and movement was eastward. North-trending normal faults, on the eastern side of Clarkston Mountain, are particularly significant. They formed as thrust faults with eastward movement. Later deformation caused reversed movement. North-trending normal faults are also present on the western side of Clarkston Mountain. The area of Junction Hills is separated from Clarkston Mountain by an east-west normal fault. The Oquirrh Formation is faulted down, on the south, opposite Cambrian formations. Marginal normal faults extend along the western and eastern sides of Clarkston Mountain and the Junction Hills. Movement on these faults produced the great relief of Clarkston Mountain.

The folding and thrust faulting occurred during the Laramide deformation. This deformation is considered to have started by early Cretaceous time and to have continued into early Tertiary. Normal faulting, including reversed movement on original thrust faults, represents Basin and Range faulting. This faulting began early in the Tertiary period and continues at the present time.
INTRODUCTION

Purpose and Scope

This study of the southern part of Clarkston Mountain, Malad Range, Utah, was undertaken for the purpose of improving our understanding of the structural events of north-central Utah. A large-scale geologic map was constructed (Plate 1).

Location and Accessibility

The mapped area is located in north-central Utah (Figure 1). It represents part of the Portage quadrangle, on the west, and part of the Clarkston quadrangle, on the east. These quadrangles are 7.5 minute topographic maps published by the Geological Survey of the U. S. Department of Interior. The mapped area is 8.3 miles wide in the east–west direction and 4.0 miles long in the north–south direction. The northern boundary is 4.7 miles south of the Utah–Idaho border.

The Short Divide road extends from Clarkston, Utah, on the eastern side of Clarkston Mountain to Plymouth, Utah, on the western side. The low hills, south of the road, have been referred to as the Junction Hills (Williams, 1948, p. 1126).
Figure 1. Index map of central part of northern Utah showing location of the southern part of Clarkston Mountain, Malad Range, Utah.
Physiographic Features

The southern part of Clarkston Mountain is bounded on the west by Malad Valley and on the east by Cache Valley. Wellsville Mountain is 7.5 miles south of the southern part of Clarkston Mountain. The Bear River Range, east of Cache Valley, rises to an elevation of 9,980 feet; whereas, Cache Valley has a low elevation of 4,417 feet in the west-central part. Malad Valley, west of the mapped area, has a low average elevation of 4,300 feet.

The elevation of the southern part of the mapped area, on the main ridge between Bensons Hollow and Bob Archibald Hollow, is 5,931 feet. At the point where the Short Divide road crosses the ridge, the mountain rises sharply up to an average elevation of 7,500 feet. Gunsight Peak, elevation 8,244 feet, is the highest point in the mapped area.

Field Work

Field research was conducted in 1971 and 1972. Geologic features were plotted on aerial photographs in the field and the data were transferred to a topographic base map at a scale of 1:12,000.

Previous Investigations

Hanson (1949) studied the stratigraphy and fossil fauna of Clarkston Mountain and produced a small-scale geologic map. Ross (1951) also worked on Clarkston Mountain where he measured a section of the Garden City Formation
and recognized trilobite zones. Williams (1948) studied the Paleozoic rocks of the Logan quadrangle. He re-evaluated his findings in 1958 (Williams, 1958). Later, he studied the Lake Bonneville Group of southern Cache Valley (Williams, 1962).

The northern part of Clarkston Mountain, Utah–Idaho, was mapped by Burton (1973). The central part of the Malad Range, north of Clarkston Mountain, was mapped by Prammani (1957), Murdock (1961), and Wach (1967). The northern part of Wellsville Mountain was mapped by Beus (1958).

STRA\vIGRAPHIC UNITS

General Statement

The southern part of Clarkston Mountain consists of stratigraphic units that range in age from Middle Cambrian to Pennsylvanian (Table 1). The Salt Lake Formation of Tertiary age lies unconformably on the Paleozoic rocks. The Quaternary Lake Bonneville Group, in turn, lies unconformably on the Salt Lake Formation. Holocene deposits of colluvium and alluvium lie on rocks of Paleozoic age, the Salt Lake Formation, and the Lake Bonneville Group.

The Brigham, Langston, Ute, Blacksmith, and Bloomington Formations of Cambrian age do not crop out in the mapped area, but they are exposed north of the mapped area. Rocks of Permian age, as well as rocks of Mesozoic age, do not occur in the mapped area.

Cambrian System

Nounan Formation

The Nounan Formation, in Clarkston Mountain, is 1,408 feet thick (Hanson, 1949, p. 24-25). It is divided into two members as follows: (1) lower thick- to massive-bedded dark-gray dolomite, 908 feet thick, and (2) upper thin- to medium-bedded light- to dark-gray limestone, at least 500 feet thick.

Maxey (1941, p. 28-32) measured the Nounan Formation at High Creek, in the Bear River Range, and reported a thickness of 1,125 feet. His section may
Table 1. Stratigraphic units of Paleozoic age, southern part of Clarkston Mountain, Malad Range, Utah.

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<th>Unit</th>
<th>Lithology</th>
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<td>Oquirrh Formation</td>
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<td></td>
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<tr>
<td>West Canyon Member</td>
<td>Blue-gray limestone</td>
<td>1,307^d</td>
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<td><strong>Ordovician and Silurian Systems</strong></td>
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<tr>
<td>Fish Haven and Laketown Formations</td>
<td>Dark-gray and light-gray dolomite</td>
<td>1,599^e,f</td>
</tr>
<tr>
<td><strong>Ordovician System</strong></td>
<td></td>
<td></td>
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<tr>
<td>Swan Peak Formation</td>
<td>Light-gray orthoquartzite</td>
<td>574^d</td>
</tr>
<tr>
<td></td>
<td>Interbedded brown orthoquartzite and green shale</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interbedded brown sandstone and gray shale</td>
<td></td>
</tr>
<tr>
<td>Garden City Formation</td>
<td>Cherty limestone</td>
<td>1,760^e</td>
</tr>
<tr>
<td></td>
<td>Intraformational conglomeratic limestone</td>
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<td><strong>Cambrian System</strong></td>
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<td>St. Charles Formation</td>
<td></td>
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<tr>
<td>Upper Member</td>
<td>Light-gray and medium-gray dolomite</td>
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<td></td>
<td>Silty limestone</td>
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<td>Worm Creek Member</td>
<td>Quartzite and calcareous sandstone</td>
<td>75^a,b</td>
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<td>Red quartzite</td>
<td></td>
</tr>
<tr>
<td>Nounan Formation</td>
<td>Medium-gray limestone</td>
<td>1,408^a</td>
</tr>
<tr>
<td></td>
<td>Dark-gray dolomite</td>
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a. Hanson (1949)  
b. Maxey (1941)  
c. Ross (1951)  
d. James (1973)  
e. Williams (1948)  
f. Budge (1966)  
g. Beus (1968)
be summarized as follows: (1) lower light-gray dolomite, 635 feet thick, and (2) upper light-gray dolomite with interbedded dark-gray limestone, 490 feet thick.

The contact of the Nounan with the underlying Bloomington Formation of Cambrian age is not exposed in the mapped area. The lower part of the Nounan, in the mapped area, consists of dark-gray dolomite. The upper Nounan is interbedded argillaceous dolomite and limestone that grades into the Worm Creek Member of the St. Charles Formation. The best exposure of the upper contact is east of Water Canyon.

The Nounan Formation is of Middle Cambrian age (Maxey, 1941, p. 62).

**St. Charles Formation**

The St. Charles Formation, in Clarkston Mountain, is 1,073 feet thick (Hanson, 1949, p. 32). It consists of three members as follows: (1) lower gray quartzite, 75 feet thick, (2) light-gray limestone with stringers of chert, 368 feet thick, and (3) upper light- to medium-gray dolomite, 630 feet thick. The quartzite represents the Worm Creek Quartzite Member. The St. Charles Formation at High Creek, in the Bear River Range, is 1,015 feet thick (Maxey, 1941, p. 26-28). There, it is divided into three units as follows: (1) lower light-gray quartzite, 75 feet thick, (2) light- to dark-gray limestone, 295 feet thick, and (3) upper medium-gray dolomite, 645 feet thick.

The basal Worm Creek Quartzite Member of the St. Charles Formation grades downward into the Nounan Formation. The middle member, which consists of light-gray limestone with stringers of white chert, is generally poorly
exposed. The upper member of light- to medium-gray dolomite forms massive cliffs. In places, especially near the top, it has stringers of white and black chert. The Garden City Formation of Ordovician age conformably overlies the St. Charles.

The upper member of the St. Charles Formation is of Late Cambrian age (Maxey, 1941, p. 62).

**Ordovician System**

**Garden City Formation**

The Garden City Formation is well exposed, on the western side of Clarkston Mountain, from the northern boundary of the mapped area southward to Water Canyon. It is 1,805 feet thick (Hanson, 1949, p. 41). Four members are recognized: (1) lower medium-gray limestone and limestone intraformational conglomerate, 900 feet thick, (2) silty and argillaceous limestone, 583 feet thick, (3) limestone and black chert, 170 feet thick, and (4) upper medium-gray dolomite with some chert, 152 feet thick.

The Garden City rests conformably on the St. Charles Formation. The lower contact is at the top of the dolomite of the St. Charles and at the base of the limestone of the Garden City. The upper contact is at the top of the dolomite of the Garden City and at the base of the black shale of the overlying Swan Peak Formation. The upper contact is also conformable.

The Garden City Formation is of Early and Middle Ordovician age (Ross, 1951, p. 13).
Swan Peak Formation

The Swan Peak Formation crops out on the western and southern sides of Gunsight Peak. It is at least 606 feet thick (Hanson, 1949, p. 44). Three members are recognized as follows: (1) lower black shale, 50 feet thick, (2) brown, reddish-gray, and purplish-gray orthoquartzite, 156 feet thick, and (3) upper white quartzite, at least 400 feet thick. James (1973, p. 245-247) measured 574 feet of Swan Peak southwest of Gunsight Peak. His members are as follows: (1) lower orthoquartzite and gray shale, 79 feet thick, (2) orthoquartzite and green shale, 29 feet thick, and (3) upper light-gray orthoquartzite, 466 feet thick.

The lower contact of the Swan Peak Formation is at the top of the dolomite member of the Garden City Formation; however, the lower shale member of the Swan Peak is not well exposed. The upper contact is at the top of the quartzite of the Swan Peak and at the base of the dolomite of the overlying undifferentiated Fish Haven and Laketown Formations. The upper contact is regarded as an unconformity (Hanson, 1949, p. 43).

The outcrop of Swan Peak Formation and undifferentiated Fish Haven and Laketown Formations, on the peak east of Gunsight Peak, rests with structural discordance on the St. Charles Formation. There, the lower and middle members of the Swan Peak are missing.

Brecciated quartzite and dolomite, at Short Divide, are also structurally discordant with the underlying rocks. They represent the upper part of the Swan Peak Formation and the lower part of the undifferentiated Fish Haven and
Laketown Formations. This quartzite was mapped as the Worm Creek Member of the St. Charles Formation by Hanson (1949, Plate 27); however, it underlies the dolomite in normal stratigraphic succession and contains worm burrows that are characteristic of the Swan Peak.

The Swan Peak Formation is of earliest Middle Ordovician age (Ross, 1951, p. 33).

Ordovician and Silurian Systems

Fish Haven and Laketown Formations

The Fish Haven and Laketown Formations are considered here as a unit due to their gradational character (Williams, 1948, p. 1137; Budge, 1966, p. 15; Hanson, 1949, p. 47). The unit of undifferentiated Fish Haven and Laketown Formations forms Gunsight Peak.

The Fish Haven Formation is dark-gray dolomite (Hanson, 1949, p. 46). It is 50 feet thick. The Laketown Formation, as described by Hanson (1949, p. 49), consists of two members as follows: (1) lower interbedded dark-gray and light-gray dolomite, and (2) upper light- to medium-gray dolomite. The upper part of the undifferentiated Fish Haven and Laketown Formations forms the top of Gunsight Peak; therefore, the thickness is not known for the area of Clarkston Mountain. Williams (1948, p. 1138) found 1,150 feet of Laketown in Green Canyon, northeast of Logan, Utah. There, it rests on the Fish Haven Formation, which is 140 feet thick (Williams, 1949, p. 1137). Thus, the
The total dolomite section in Green Canyon, representing the Fish Haven and Lake-
town Formations, is about 1,290 feet thick. The original thickness, in the
area of Clarkston Mountain, was probably not greatly different.

The Fish Haven is Late Ordovician in age (Hanson, 1949, p. 46-48). Budge (1966, p. 46-48) assigned the lower Laketown to Late Ordovician and the remainder to Early and Middle Silurian.

Peninsylvanian System

Oquirrh Formation

Williams (1958, p. 35) recognized the Oquirrh Formation on the eastern side of the Pissah Hills and northward in Wellsville Mountain. Earlier, Williams (1948, p. 1143) referred to the Peninsylvanian strata of the Logan quadrangle as the Wells Formation. Beus (1968, p. 797-801) recognized the Oquirrh Formation in Samaria Mountain, Utah-Idaho; however, the section is incomplete. Two autochthonous members are present as follows: (1) lower West Canyon Limestone Member, 1,307 feet thick, and (2) upper limestone and orthoquartzite member, at least 1,198 feet thick. The West Canyon Member consists of gray cherty limestone of Peninsylvanian age. It is overlapped unconformably by the upper member of Permian age (Beus, 1968, p. 800). The middle part of the Oquirrh Formation, on the western side of Samaria Mountain, is allochthonous.

In the Junction Hills, the Oquirrh is exposed from just south of Short Divide southward for 1.4 miles. Only the basal West Canyon Member is present.
Conspicuous cherty limestone and red quartzite form the section. Fossil corals and brachiopods are present in the limestone. The Salt Lake Formation lies unconformable on the Oquirrh in the Junction Hills.

**Tertiary System**

**Salt Lake Formation**

Williams (1948, p. 1147) recognized the Salt Lake Formation in the Junction Hills, Wellsville Mountain, and Cache Valley as tuff, tuffaceous sandstone, and conglomerate. Adamson, Hardy, and Williams (1955) defined the Salt Lake Group with three formations: (1) lower Collinston Conglomerate, (2) Cache Valley Formation, and (3) upper Mink Creek Conglomerate. Later, Williams (1962, p. 133) redefined the Salt Lake and reduced it to formation status having three members: (1) lower conglomerate unit, (2) tuff unit, and (3) upper conglomerate and sandstone unit.

In the Junction Hills, the lower conglomerate of Williams is missing. A bed of pebble conglomerate, 3-6 feet thick, overlies the Oquirrh Formation. It is overlain by a thick section of tuffaceous limestone. This is evidently the tuff unit of Williams.

The Salt Lake Formation overlaps Paleozoic rocks on the southern side of Clarkston Mountain. No basal conglomerate is present.

The Salt Lake Formation, on the southern part of Clarkston Mountain, is middle or late Pliocene in age (Williams, 1958, p. 73). Adamson, Hardy, and
Williams (1955, p. 2) considered the Salt Lake Formation to be of Miocene and Pliocene age.

**Quaternary System**

**Lake Bonneville Group**

Hunt, Varnes, and Thomas (1953) established the Lake Bonneville Group in northern Utah Valley in central Utah. It consists of three formations as follows: (1) lower Alpine Formation, (2) Bonneville Formation, and (3) upper Provo Formation.

Williams (1962, p. 137) recognized the Lake Bonneville Group in Cache Valley, Utah. He grouped the Alpine and Bonneville Formation as an undifferentiated unit. It consists of local deposits of gravel and more extensive deposits of silt and fine sand. The Provo Formation has a gravel and sand member and silt and clay member. The members intertongue and intergrade.

In the mapped area, the Lake Bonneville Group generally overlaps the Salt Lake Formation; however, along the western side of Clarkston Mountain, it rests on Paleozoic rocks. The Lake Bonneville Group is well exposed in road cuts west of Short Divide. North of Plymouth, along U.S. Highway 191, it is exposed in several gravel pits.

Conspicuous shoreline terraces of Lake Bonneville extend along the western margin of Junction Hills. Similar terraces are found on the eastern side of Junction Hills. A prominent embankment is present west of Clarkston. Northward
along the eastern slope of Clarkston Mountain, the shoreline is relatively inconspicuous.

The Lake Bonneville Group is Pleistocene in age (Williams, 1962, p. 131).

**Colluvial deposits**

Colluvial deposits are composed of unconsolidated material that mantles slopes. They consist of boulders, cobbles, and pebbles, as well as fine-grained material.

Boulders, cobbles, and pebbles of quartzite and dolomite, in a fine-grained matrix, are present in the saddle east of Gunsight Peak. This material was derived from the displaced block of Swan Peak and Fish Haven Formations on the eastern side of the saddle.

A deposit of boulders and cobbles, east of Short Divide, was derived from the displaced block of the Swan Peak Formation. A large area of colluvial deposits extends along the eastern side of Clarkston Mountain. There, brown soil, which contains scattered cobbles, is present between the highest shoreline of Lake Bonneville and the mountain front.

**Alluvial deposits**

Alluvial deposits, in the mapped area, are mostly alluvial fans. The fans are composed of rounded to subrounded boulders of dolomite, quartzite, and some limestone. Brown-weathering fine-grained material forms the matrix.
Notable alluvial fans are present at the mouths of Green and Winter Canyons on the eastern side of Clarkston Mountain. Large boulders of dolomite are common in the fan at the mouth of Winter Canyon.

The alluvial deposits are of Holocene age.
STRUCTURAL FEATURES

Regional Setting

The southern part of the Malad Range separates Cache Valley, on the east, from Malad Valley, on the west. Hanson (1949, p. 68–70) reported that the southern part of Clarkston Mountain displays block faulting that is typical of Basin and Range structure. The Junction Hills is a horst, with east-dipping rocks, which is bounded by youthful fault scarps (Williams, 1948, p. 1150).

The Bannock thrust zone, east of the mapped area, extends along the eastern side of the Bear River Range. Armstrong and Cressman (1963, p. 6) concluded that it is an imbricate thrust zone. The Paris thrust fault, on the north, and the Woodruff thrust fault, on the south, are major faults of the Bannock thrust zone. These thrust faults dip west. The Paris thrust fault, near Nounan, Idaho, places the Cambrian Brigham Formation on the Triassic Thaynes Formation. This represents a stratigraphic throw of about 20,000 feet (Armstrong and Cressman, 1963, p. 7). The Woodruff thrust fault also places the Brigham Formation on the Thaynes Formation.

Another thrust zone, in the area of Ogden, Utah, was described by Eardley (1944, p. 847–849). He reported three east-dipping thrust faults. The two lower thrust faults, known as the Taylor and Ogden, cut Precambrian and Cambrian rocks. The higher Willard thrust fault places Precambrian rock over Cambrian
and Mississippian rocks. Eardley (1944, p. 866) extended the Willard thrust fault eastward to the Woodruff thrust fault.

Crittenden (1972, p. 2872-2873) determined that eastward thrusting produced the Willard thrust fault. He accepted the concept of a connection of the Willard and Woodruff thrust faults (Crittenden, 1972, p. 2876). Crittenden (1972, p. 2879) concluded that the area from Wellsville Mountain eastward through the Bear River Range is a gently downwarped thrust plate.

Thrust and Strike-slip Faults

General statement

Thrust faults and strike-slip faults are here associated because they probably formed simultaneously. Only one low-angle thrust fault is present in the mapped area. A number of other thrust faults were formed; however, they were later subjected to reversed movement. They are mapped as normal faults.

Williams (1948, p. 1151) and Hanson (1949, p. 79) considered the possibility that the southern part of Clarkston Mountain and Wellsville Mountain are part of a large overthrust sheet with the intervening Junction Hills constituting the footwall. No such thrust fault is recognized between the Junction Hills and Clarkston Mountain.

Low-angle thrust fault

A low-angle thrust fault is exposed on the eastern side of Clarkston Mountain at a point located 0.2 mile west of the mouth of Old Canyon. It extends
southward to South Canyon. At the mouth of South Canyon, it strikes N. 20° W. and dips 33° W. The Garden City Formation, on the west, has been thrust eastward over the St. Charles Formation. The St. Charles dips 54° E. This high dip is interpreted as drag beneath the fault.

**Strike-slip fault**

A strike-slip fault, which trends N. 84° W., is present on the eastern side of Clarkston Mountain. It extends from the lower part of Old Canyon northwestward into the upper part of Green Canyon. On the ridge north of Old Canyon, it is vertical and exhibits horizontal slickensides.

This fault cuts east-dipping St. Charles and Garden City Formations. It intersects the eastern marginal normal fault of Clarkston Mountain in lower Old Canyon. Westward, it evidently terminates in upper Green Canyon at a major north-trending normal fault. The block on the northern side of this fault may have been displaced eastward relative to the block on the southern side. This is suggested by the apparent offset of a west-dipping fault.

**Structural interpretations**

The low-angle thrust fault, on the eastern side of Clarkston Mountain, is the only thrust fault in the mapped area. The west dip, at a low angle, and the eastward movement are in accordance with evidence of thrust faulting in the northern part of Clarkston Mountain. A number of north-trending normal faults, in the
mapped area, represent original west-dipping thrust faults. Reversed movement has destroyed the thrust relationship. Thus, it is appropriate to represent them as normal faults.

The westward termination of the strike-slip fault at a north-trending normal fault that represents an original thrust fault suggests that the thrust fault formed after the strike-slip fault. The apparent offset of a west-dipping fault by the strike-slip fault indicates that the strike-slip fault formed after an original thrust fault. Several other west-dipping faults terminate at the strike-slip fault. Thus, it may be concluded that the strike-slip faulting and the thrust faulting were essentially contemporaneous.

**Normal Faults**

**General statement**

The normal faults are readily grouped as follows: (1) eastern north-trending normal faults, (2) western north-trending normal faults, (3) east-trending normal faults, and (4) marginal normal faults. The eastern north-trending normal faults probably all formed as west-dipping thrust faults. They were later subjected to reversed movement and are, therefore, represented as normal faults. The western north-trending normal faults formed as original normal faults.
Eastern north-trending normal faults

Four north-trending normal faults are exposed on the ridge northwest of Short Divide. They all dip about 50° W. and place the Ordovician Garden City Formation down, on the west, next to the Cambrian St. Charles Formation, on the east. The faults offset the contact between the Cambrian Nounan and St. Charles Formations. The faults are terminated at their northern ends by an east-trending strike-slip fault. Immediately west of the westernmost fault, the Garden City dips 50° E. This attitude is interpreted as drag on an original thrust fault.

Another north-trending normal fault is exposed on the ridge north of lower Winter Canyon. It extends southward to the ridge north of lower Old Canyon. On the ridge north of lower Winter Canyon, the fault dips 40° W. and places the Garden City Formation down, on the west, next to the St. Charles Formation, on the east. In lower Old Canyon, the fault is within the Garden City on the ridge north of the canyon (Figure 2). The St. Charles and Garden City Formations, east of the fault, dip 55° to 60° E. West of the fault, the Garden City dips about 40° E. The steeper attitude, beneath the fault, is regarded as drag, which was formed by thrust faulting that preceded the normal faulting.

A mile west of the mouth of Winter Canyon, another north-trending normal fault is exposed. On the northern side of upper Winter Canyon, the fault surface is exposed and dips about 34° W. There, the upper member of the Garden City is faulted down, on the west, next to the lower member of the Garden City. On the ridge on the southern side of upper Winter Canyon, the Garden City
Figure 2. North-trending normal fault, on northern side of Old Canyon, on eastern side of Clarkston Mountain; view north. Fault dips west and is within the Garden City Formation.
is faulted down, on the west, next to the St. Charles on the east. On the main ridge east of Water Canyon, the fault changes trend and heads to the southwest. There, reversed movement placed the lower part of the St. Charles down, on the north, opposite the upper part of the Nounan.

A north-trending normal fault is present on the eastern side of the ridge that is located northeast of Gunsight Peak. This fault extends from the northern margin of the mapped area southward into the upper part of Winter Canyon. It crosses the ridge at the head of Winter Canyon and continues into Water Canyon. There, it intersects the Gunsight fault. The fault strikes N. 6° W. and dips approximately 70° W. At the northern margin of the mapped area, the St. Charles Formation, on the west, opposes the Garden City Formation, on the east. Throughout the remainder of the upper part of Winter Canyon, it is within the St. Charles Formation. On the eastern side of Water Canyon, the St. Charles is faulted down, on the west, next to the upper part of the Nounan Formation. This fault is well exposed only on the ridge east of Water Canyon.

The Gunsight fault, a north-trending normal fault, extends from the northern boundary of the mapped area southward through the saddle east of Gunsight Peak into Water Canyon. It is not exposed in Water Canyon; however, stratigraphic differences on opposite sides of the canyon show the presence of a fault. Generally, the Gunsight fault dips 40° W. and places the undifferentiated Fish Haven and Laketown Formations down, on the west, next to the St. Charles in upper Elgrove Canyon north of Gunsight Peak (Figure 3). In upper Water Canyon, the undifferentiated Fish Haven and Laketown Formations are faulted down,
Figure 3. Gunsight fault in upper Elgrove Canyon; view south. Fault dips west and extends diagonally from the saddle, between the prominent peaks, to the lower right. Gunsight Peak, on the right, is capped by the Laketown Formation. Peak on left consists of Swan Peak Formation and undifferentiated Fish Haven and Laketown Formations, near the top, resting on the Garden City Formation, in the smooth slope.
on the west, opposite Nounan and St. Charles (Figure 4). There, the Gunsight fault has at least 4,900 feet of displacement. In middle Water Canyon, Garden City and Swan Peak are down, on the west, next to Nounan. The reversed movement was down on the western side; however, earlier thrust faulting produced this fault.

**Western north-trending normal faults**

A north-trending normal fault extends from the mouth of the Left and Right Forks of Dutchmans Canyon southward to the mouth of Little Canyon. It strikes N. 10° W. and dips approximately 39° W. On the ridge north of Little Canyon, the Worm Creek Member of the St. Charles Formation is faulted down, on the west, next to the Nounan Formation.

A north-trending normal fault, located 0.1 mile east of the mouth of Castlegate Canyon, extends southward to a small canyon between Little and Cedar Canyons. The fault trends N. 10° W. and dips approximately 55° W. In Castlegate Canyon, the lower part of the St. Charles Formation is faulted down, on the west, next to the middle part of the St. Charles. In the Left and Right Forks of Dutchmans Canyon, the fault is within the Nounan Formation. In Little Canyon, the St. Charles is faulted down, on the west, next to the Nounan and St. Charles.

A north-trending normal fault extends northeastward up Cedar Canyon to a point located southwest of Gunsight Peak and thence northward. It strikes N. 9° W. and dips about 50° W. The fault places the St. Charles, Garden City,
Figure 4. Gunsight fault in Water Canyon; air view northeast. Gunsight Peak, capped by undifferentiated Fish Haven and Laketown Formations, is at upper left. Gunsight fault, indicated by arrow, dips west. North-trending normal fault intersects Gunsight fault at upper right. It places the St. Charles Formation (Csc), on the left, against the Nounan Formation (Cn), on the right.
Swan Peak, and undifferentiated Fish Haven and Laketown Formations down, on the west, next to the same sequence of formations on the east. A small outcrop of Swan Peak is located, east of the fault, in the upper part of the Left Fork of Dutchmans Canyon. In upper Castlegate Canyon, the Swan Peak is faulted down, on the west, next to the Garden City and Swan Peak Formations on the east. At the northern margin of the mapped area, this fault is within the Garden City Formation.

Another north-trending normal fault extends up Mine Hollow, which is located east of Cedar Canyon. The St. Charles, Garden City, Swan Peak, and undifferentiated Fish Haven and Laketown Formations are faulted down, on the west, next to the same sequence of formations on the east. Southwest of Gunsight Peak, this fault is within the undifferentiated Fish Haven and Laketown Formations.

East-trending normal faults

Two east-trending normal faults are exposed in the Short Divide area. The northern fault terminates the lower Paleozoic rocks of Clarkston Mountain. It extends from east of Short Divide westward for 5 miles and displaces the Salt Lake Formation. At a point located 0.2 mile west of Short Divide, the Salt Lake, south of the fault, dips approximately 70° S. This is inferred as drag on the down side of the fault. The southern fault, south of the television tower at Short Divide, separates the Salt Lake Formation, on the north, from the Oquirrh Formation, on the south (Figure 5). The fault surface is exposed and is vertical.

Hanson (1949, p. 74-75) reported only one major fault at Short Divide. He concluded that the fault has a stratigraphic throw of at least 10,000 feet.
Figure 5. East-trending normal fault south of Short Divide; air view northeast. Salt Lake Formation (Tsl), on the left, is faulted against the Oquirrh Formation (Po), on the right. Salt Lake Formation unconformably overlies the Oquirrh Formation at upper right.
Marginal normal faults

A normal fault marks the western margin of the Malad Range. Williams (1948, p. 1151) and Hanson (1949, p. 70-71) recognized this fault and concluded that it has a stratigraphic throw of about 3,000 feet. A fault scarp extends along the western margin of Clarkston Mountain. The Lake Bonneville Group overlaps Paleozoic rocks east of this fault.

Williams (1948, p. 1157) and Hanson (1949, p. 71) also recognized the eastern fault along the margin of Clarkston Mountain. The fault scarp is not as obvious on Clarkston Mountain as it is on the Junction Hills. On the Junction Hills, the eastern fault scarp cuts the Salt Lake Formation. Cook and Smith (1967, p. 697-698) described the eastern fault as a major fault zone.

A fault scarp, north of the town of Plymouth, exposes the Salt Lake Formation (Figure 6). The fault starts north of Little Canyon, swings southeast, and thence southward along the western side of Junction Hills (Figure 7). It cuts the Oquirrh Formation in Junction Hills.

Structural interpretations

The relief of Clarkston Mountain is due to relative collapse along marginal normal faults on the western and eastern sides. These faults are probably nearly vertical. In the northern Utah area, normal faults are nearly vertical (Galloway, 1970; Williams, 1948; Beus, 1968; Armstrong and Cressman, 1963).

The north-trending normal faults, on the eastern side of Clarkston Mountain, represent original west-dipping thrust faults on which reversed movement
Figure 6. Scarp of marginal normal fault southwest of Gunsight Peak; air view northeast. Salt Lake Formation (Tsl), in smooth slope on the right, unconformably overlaps the east-dipping Nounan, St. Charles, and Garden City Formations of the mountains.
Figure 7. Scarp of marginal normal fault on western side of Junction Hills; view south. Fault extends up the prominent valley, on the right, and curves southward. Salt Lake Formation (Tsl) forms hills in the foreground and rests unconformably on the Oquirrh Formation (Po) to left of fault in center. Landslide of the Salt Lake Formation, beyond the fault, protrudes into the valley west of the Junction Hills.
Reverse drag is recognized above and below the fault planes. The normal fault, near the eastern marginal fault, exhibits dips of $55^\circ$ to $60^\circ$ E. in the Garden City Formation east of the fault. In the northern part of Clarkston Mountain, Burton (1973, p. 22) recognized a low-angle thrust fault that dips $30^\circ$ W. and places the Bloomington Formation over the Nounan Formation. Burton (1973, p. 24) recognized reversed movement on a normal fault that is located 0.3 mile west of the thrust fault previously mentioned. He reported that the fault dips about $40^\circ$ W. and places the Nounan Formation down, on the west, next to the Bloomington Formation, on the east. Prammani (1957, p. 48) recognized reversed movement on the Square Peak fault in Dry Canyon west of Weston, Idaho. He reported an increased dip in the Garden City near the fault.

Displaced Blocks

General statement

Displaced blocks are masses of rock that were emplaced by either thrust faulting or normal faulting. They may have moved a relatively short distance or as much as several miles.

Central part

A large mass of the Swan Peak Formation and undifferentiated Fish Haven and Laketown Formations rests on the St. Charles and Garden City Formations on the ridge east of Gunsight Peak (Figure 8). Only the upper quartzite member of the Swan Peak is present. The undifferentiated Fish Haven and Laketown
Figure 8. Gunsight Peak and peak east of Gunsight Peak; view north. Gunsight Peak, on the left consists of undifferentiated Fish Haven and Laketown Formations. Peak on the right consists of the Swan Peak Formation and undifferentiated Fish Haven and Laketown Formations, resting on the St. Charles Formation with structural discordance. Gunsight fault extends from the saddle between the peaks down Water Canyon to the lower left.
Formation strike N. $13^0\ E. and dip $20^0\ E$. On the eastern side of the Peak that is located northeast of Gunsight Peak at the northern margin of the mapped area, undifferentiated Fish Haven and Laketown Formations rest on the St. Charles Formation along a west-dipping low-angle fault.

**Southern part**

A mass of Swan Peak Formation and undifferentiated Fish Haven and Laketown Formations is located north of Short Divide. It rests on the St. Charles Formation. The underlying surface dips $20^0$ to $25^0\ S$. Quartzite of the Swan Peak strikes north and is nearly vertical. It is thrust over the undifferentiated Fish Haven and Laketown. Both the Swan Peak and undifferentiated Fish Haven and Laketown are brecciated and recemented indicating earlier movement and possible subsequent downfaulting into the present position.

**Structural interpretations**

The mass of Swan Peak and undifferentiated Fish Haven and Laketown Formations, on the ridge east of Gunsight Peak, could have been thrust eastward over the St. Charles Formation. A possible thrust fault, beneath the Swan Peak, dips $30^0\ W$. No thrust fault is recognized under Gunsight Peak on which the displaced block could have originated. It is possible that the surface under the displaced block is part of the Gunsight fault but the dip of the latter is $40^0\ W$.

The displaced block, on the southern side of Clarkston Mountain, rests on a surface that dips southward. South-dipping thrust faults are unknown in northern Utah. Normal faulting could have dropped the displaced block, northeast of Short
Divide, down into its present position. A possible normal fault dips 20° to 25° S. and separates Swan Peak, down on the south, from St. Charles on the north.

**Landslides**

**Western slope**

On the ridge between upper Little Canyon and the middle part of the Right Fork of Dutchmans Canyon, a mass of the Swan Peak Formation has moved westward over the lower member of the St. Charles Formation. The Swan Peak, in this area, consists of brecciated white quartzite. The landslide rests on a surface that slopes 40° to 45° W.

**Southern margin**

A landslide of undifferentiated Fish Haven and Laketown Formations is present, along the southern margin of Clarkston Mountain, between Mine Hollow and Bishop Canyon. The rocks dip 36° S. and are highly brecciated. A slickensided surface, exposed in a mine tunnel, strikes N. 10° E. and dips steeply south. The landslide rests on the St. Charles Formation. It is overlapped by the Salt Lake Formation.

A landslide of the Salt Lake Formation, in the southern part of the mapped area, is located west of the marginal normal fault along the outcrop of the Oquirrh Formation (Figure 7). The Salt Lake Formation of the landslide has an average dip of 25° E.
Three landslides of the Salt Lake Formation are present along the southern margin of Clarkston Mountain. The largest one is at the mouth of Water Canyon. In all cases, the source areas are evident. The landslides rest on the Lake Bonneville Group.
STRUCTURAL EVENTS

General Statement

Two major events of crustal deformation are recognized in the southern part of Clarkston Mountain and the Junction Hills. They are: (1) early thrust faulting, and (2) later normal faulting. The thrust faulting occurred during the Laramide deformation and the normal faulting represents Basin and Range faulting.

The Laramide is considered to have started by early Cretaceous time and to have extended into the early Tertiary. Armstrong and Cressman (1963, p. 14) indicated that folding in the Bear River Range and movement on the Paris thrust fault started in latest Jurassic or earliest Cretaceous time. Laramide deformation ended, in the area of the Bear River Range, by the time the Wasatch Formation of Eocene age was deposited.

Basin and Range normal faulting followed Laramide deformation. It probably started soon after the deposition of the Wasatch Formation. The Salt Lake Formation was deposited after the Wasatch and normal faulting began during its deposition. Armstrong and Oriel (1965, p. 1862-1863), in their report on the Idaho-Wyoming thrust belt, concluded that the normal faulting began during Eocene and continued to the present.
Laramide Events

Low-angle thrust faulting

The earliest structural event of the southern part of Clarkston Mountain is here identified as low-angle thrust faulting; however, related folding and strike-slip faulting are included. Folding produced the eastward dip of the Paleozoic strata of Clarkston Mountain. The west-dipping low-angle thrust fault, located on the eastern side of Clarkston Mountain between Old Canyon and South Canyon, must have formed in association with the folding. The strike-slip fault, located on the ridge north of Old Canyon, is also logically associated with this event.

The mass of Swan Peak and undifferentiated Fish Haven and Laketown Formations, on the ridge east of Gunsight Peak, rests on the St. Charles Formation. This mass is described as a displaced block. The underlying fault dips westward at a low angle. The dislocated mass may have been thrust eastward; however, no thrust fault is recognized under Gunsight Peak.

High-angle thrust faulting

The north-trending normal faults, on the eastern side of Clarkston Mountain, were high-angle thrust faults initially. Reversed movement destroyed the thrust relationship.

The four north-trending normal faults that cross the ridge north of Short Divide are believed to have formed as west-dipping thrust faults. They are all down on the west; however, the rocks immediately west of the westernmost fault
dip east. This relationship is interpreted as drag that was formed during thrust faulting.

Two major north-trending normal faults are present in the northeastern part of the mapped area. One, near the mountain front, extends from lower Winter Canyon southward to lower Old Canyon. It dips 30° W. The relatively steep eastward dip of the beds beneath this fault is regarded as drag that was produced during eastward thrust faulting. The parallel north-trending normal fault, located about a mile west of this one, is believed to have formed in the same way. Confirming details, however, are lacking.

The Gunsight fault is a north-trending normal fault. It dips 40° W. and places the undifferentiated Fish Haven and Laketown Formations down, on the west, next to the St. Charles Formation. The attitude of the fault is evidence that it formed as a west-dipping thrust fault.

**Basin and Range Events**

**Early normal faulting**

Normal faulting began after the folding and thrust faulting of Laramide deformation. The inception of normal faulting is here characterized as early normal faulting.

The marginal normal faults that extend along the western, southwestern, and eastern side of Clarkston Mountain must have formed at this time. The major east-trending normal fault, located in the Short Divide area, also must have formed
relatively early. The Pennsylvanian Oquirrh Formation, along this fault, is down, on the south, next to the Cambrian Nounan and St. Charles Formations on the north.

Reversed movement, on west-dipping thrust faults, occurred at this time. As a result, these faults are now regarded as north-trending normal faults.

Reversed movement, down on the west, occurred on each of the four north-trending normal faults that cross the ridge north of Short Divide. Thus, on the westernmost of these faults, the Garden City Formation is down, on the west, next to the St. Charles Formation. Reversed movement also took place on the two major north-trending normal faults that are present in the northeastern part of the mapped area. Movement on the Gunsight fault, which fault dips about 40° W., is also attributed to reversed movement at this time. Thus, the undifferentiated Fish Haven and Laketown Formations on Gunsight Peak oppose the St. Charles Formation on the eastern side of the Gunsight fault.

Internal north-trending normal faults, on the western side of Clarkston Mountain, are thought to have formed after substantial relative collapse of the valley area west of Clarkston Mountain. They may have been caused by slope instability along the western marginal normal fault.

The mass of Swan Peak and undifferentiated Fish Haven and Laketown Formations, located at the southern extremity of Clarkston Mountain immediately north of Short Divide, rests on the St. Charles Formation. The underlying surface dips southward at a low angle. This mass may have moved into its
present position as a result of normal faulting in association with the relative collapse of the area south of Clarkston Mountain.

**Early landsliding**

Early landsliding produced two dislocated masses of Paleozoic rocks. This landsliding took place, at least in part, during deposition of the Salt Lake Formation.

The larger landslide, located at the southern margin of Clarkston Mountain between Mine Hollow and Bishop Canyon, is overlapped by the upper part of the Salt Lake Formation. It is highly fractured and consists of undifferentiated Fish Haven and Laketown Formations.

The small landslide consists of Swan Peak Formation as well as undifferentiated Fish Haven and Laketown Formations. It rests on a ridge that extends westward from Gunsight Peak. Much canyon cutting occurred after the emplacement of this landslide.

**Later normal faulting**

Direct evidence of later normal faulting has not been identified in the mapped area; however, it is known to have continued to the present time elsewhere in the region. It seems virtually certain that the marginal normal faults have cut the Lake Bonneville Group. No recent fault scarps have been identified in area of Quaternary deposits.
Later landsliding

Later landsliding involved the Salt Lake Formation. The largest landslide, located at the western margin of the mountain at the southern margin of the mapped area, is south of the marginal normal fault. The landslide surface is not exposed. The upper margin of the landslide is coincident with the marginal normal fault. This landslide is overlapped by the Lake Bonneville Group.

The three small landslides of Salt Lake Formation, located south of Clarkston Mountain, seem to have moved over the Lake Bonneville Group. They are not displaced by the marginal normal fault.
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